PROGRESS REPORT NORSAR PHASE 3

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Royal Norwegian Council for Scientific and
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
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ABSTRACT

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discriminants.

1. ADMINISTRATION AND ECONOMY

1.1 Personnel

Mr. H. Gjøystdal took up his work again in the Research
Group 30 September after one year's leave of absence in
the army.

1.2 Property

The NORSAR Maintenance Center (NMC) at Stange had a fire
24 November. Even though the wooden part of the building
was completely destroyed, the NORSAR installations, which
were in the part of the building made of concrete, were
not seriously damaged. Only a few items of U.S. property
got lost in the fire. The loss is reported to the U.S.
Air Force (USAF) Property Administrator.

Technical Project Officer (TPO) Capt. Woodward has been
contacted due to technical problems with an IBM Card Punch

and Tape Drives. The Card Punch will be changed if a
substitute is available from U.S. Government sources.

Some excessive equipment, junction boxes, office equipment
and other miscellaneous items, have been sold or disposed
of during the reporting period. All actions are approved
by the USAF Property Administrator.

1.3 Economy

All salaries for NORSAR personnel were raised 5% from
1 December due to a general raise in the NTNF system.
The raise was compensation for the inflationary price increases
from 15 March - 15 November this year.

Economy Status:

1.	Operations and Maintenance		
	1.1 Data Processing Center	$ 140.888	
	1.2 Field Installations	$ 26.240	
	1.3 Data Communications	$ 20.647	$187.775
2.	Research and Development		$ 13.193
3.	Administration		$ 25.559
			$226.527

2. ARRAY MONITORING AND FIELD INSTALLATIONS

Compared with last quarter of 1973, the maintenance activity
has been low (28 maintenance visits this quarter compared
with 56 last quarter of 1973). A small increase in the
number of channels with characteristics outside tolerance
limits has been observed this period from six channels as
of 1 October to fourteen at the end of the period. This is
mainly caused by an increase in the 'trigger threshold'
for maintenance visits to the subarrays in order to save
manpower and funds.

The NORSAR Analog SP Station was moved to NMC 11 November. Regular operation was resumed 22 November after some problems with the timing had been solved. A report on the technical details will be issued.

The communication line connecting NORSAR Data Processing Center (NDPC) to the simulated subarray at NMC has been down since 24 November due to the fire at NMC.

2.1 NDPC Activity

An option for easy access to the model parameters at three different points in the data channels has been implemented in CHANEVSP/LP analysis programs.

A data channel response program, giving the theoretical ground displacement for a given frequency, has been completed.

2.2 Field Maintenance

The snow conditions have prevented repair of broken cables at 10C04, 05, 06. After two unsuccessful attempts, this work is postponed until the sites can be reached by snow-vehicles. In addition to routine maintenance, five short period Line Termination Amplifiers have been replaced due to presampling filter faults. One short period seismometer (02C02) was replaced 5 December as the damping and natural frequency were outside the tolerance limits.

3. COMPUTER CENTER OPERATION AND DATA PROCESSING

3.1 Data Center Operation

No single long-duration machine stops occurred in the period. The various down times in the table below are accounted for by several short stops due to faulty components, power failures and scheduled maintenance. Tapes and tape

drives caused some concern as excessive data-checks occurred. Rewinding/cleaning of stored tapes before (re)use was started in November. This, together with an intensified tape drive check program, seems to have had a corrective result.

Total DP non-recording time in the quarter: 16 hours (0.7%)
SPS down time   16 hours (0.7%)
A Computer down time   16 hours (0.7%)
B Computer down time   28 hours (1.25%)

Average communication line down time (22 lines) 14 hours (0.64%).

The Trans-Atlantic and London links performed satisfactorily with 1 and 3 registered short breaks respectively.

The ARPANET Terminal Interface Processor (TIP) was routinely restarted 7 times in the period.

Approximately 3400 job shop programs were run.

3.2 Programming Efforts

The following programs were developed in this period:
- a program computing the phase and normalized amplitude of the theoretical NORSAR short or long period data channel ground displacement response, for a given frequency
- a set of programs performing Data Retention on the NORSAR Low Rate tapes
- a set of subroutines to facilitate the use of disk pack extents as intermediate storage for FORTRAN jobs
- a program for computing autoregressive coefficients of power spectral estimates.

Also, a program that selects earthquakes from the CGS bulle-
tin tapes has been adapted to NORSAR processing environments.
The 4th edition of the IMSL Library 1 (International Mathe-
matical and Statistical Libraries, Inc.) has been received
and implemented.

3.3 Detection and Event Processing

A floating threshold procedure has been implemented in the
Detection Processor. The current value of the noise stability,
computed continuously, is transmitted to the Shared Disk Pack
Signal Arrival File with each coherent detection.

In the Event Processor (EP), the noise stability (STAB)
received from the Detection Processor via the Shared Disk
pack Signal Arrival File entries, is used together with a
desired false alarm rate (FAR), inserted by the operator
at startup time, to compute a time-varying pre-threshold
value for the signal-to-noise ratio of the coherent detec-
tions. The formula used is:

$$TH(dB) = 12.08 - 0.89 \cdot \log(FAR) - 0.18 \cdot STAB$$

A new value of this pre-threshold is computed each time
the value of the stability changes. The actual computation
takes place in a separate FORTRAN overlay phase, loaded
by the EP controller each time it is used. Based on two
weeks of operation in December, we can already conclude
that the floating threshold procedure has been successful.
The number of false alarms in EP is now practically con-
stant, regardless of noise condition, and this first of
all means more efficient data handling, probably also a
few more events. It remains to see how the procedure works
for extremely low noise levels, i.e., high stability.

A new package has been implemented in EP. It will be
executed for coherent detections with signal-to-noise
ratios in an interval just above the (time-varying) pre-
threshold. Depending on the significance of a statistical
test, calculation of optimum subarray beam weights, and
a subsequent array beamforming with these weights, is
performed. Two additional statistical tests are performed.
The results of all the three tests and the optimum weights
are printed in the Summary Report for each event, to aid
the analyst in his decision. Also, the optimally weighted
array beam is plotted on the event's plot panel. Three
weeks of operation in December has shown that the package
is useful in identifying doubtful events. However, it seems
difficult to circumvent the basic problem that signals
and very "unlikely" noise wavelets overlap in statistical
properties. Further evaluation will be concentrated on
the use of the computed subarray weights in relation to
the known weights for any particular seismic region.

3.4 The NORSAR Terminal Interface Message Processor (TIP)
Connection
The use of the ARPANET terminal attachment from NORSAR in
this quarter does not differ from earlier reported use.
It consists of the following:

-    Routine transmission of the NORSAR bulletin to the
     message file of the U.S. Geological Survey on the
     OFFICE-1 computer at Stanford
-    Information exchange with Seismic Data Analysis
     Center (SDAC), Lincoln Laboratory's Seismic Dis-
     crimination Group, and other institutions more
     sporadically. This activity is based on our account
     on the SRI-ARC (Stanford Research Institute's Aug-
     mentation Research Center) computer and the use of
     its facilities and resources.

Other agencies than the USGS have lately shown an interest
in accessing our bulletin via the ARPANET. One way to do
this, preventing extra work, would be to store our bulletins
as files on some Host computer in the network, and make
these accessible to interested parties. A positive side
effect of this arrangement would be easier internal
management (creation, updating, sorting) of the bulletins.

The specification of the special high level protocol for
data exchange between the SDAC Communications and Control
Processor and a Site was received in October. A study has
been initiated for the purpose of arriving at design
specifications for the on-line Network Control Program,
subject to the constraints of the protocol and the Detection
Processor environment.

4. RESEARCH AND DEVELOPMENT

A study of statistical methods to use in signal-noise
classification problems has resulted in some additional
tests implemented in the Event Processor. A study of
precursors to PP has been finished. A power plant near
14C is producing a strong steady state noise component
at this subarray. This, however, has the advantage that
it can be used for monitoring in situ stress changes.
Finally it has been found that autoregressive analysis
of P-wave signals may be used for short period discrimination.

4.1 Signal-Noise Classification

Three statistical tests, Sign-Bit Semblance, Binomial and
Student's t-test (Fyen et al, 1974) have been evaluated
to test the hypothesis whether a wavelet triggering the
event detector has its origin in a real earthquake or not.
Sign-Bit Semblance measures the signal similarity across
the array. Binomial and Student's t-test are computed from

optimum amplitude weights, which are an estimate of the
amplitude factor, γ_j, in the model $Y_j = \gamma_j S + n_j$, where
Y_j is the recorded data on the j-th sensor, S a signal
part and n_j a noise part. For noise wavelets, the amplitude
weights will be random in sign and size, while for P-waves
the $\hat{\gamma}_j$-weights match the amplitude pattern in the region
in question. However, for events with a signal-to-noise
ratio as small as 3.6-4.0 units, the $\hat{\gamma}_j$-weights contain
reliable amplitude information for the "best" subarrays
only, and the correspondence between the observed $\hat{\gamma}_j$-weights
and the known amplitude pattern for larger earthquakes is
small, a problem which will be investigated further. Also
for some extreme cases, noise has the same characteristics
as an earthquake signal, as seen in Fig. 4.1 where the
best statistics accepted the event, but these cases may
be eliminated by the analyst due to his experience of
earthquake occurrence and signal shape. As noted in
section 3.3, the test statistics are included in the
Event Processor, which will give more experience in the
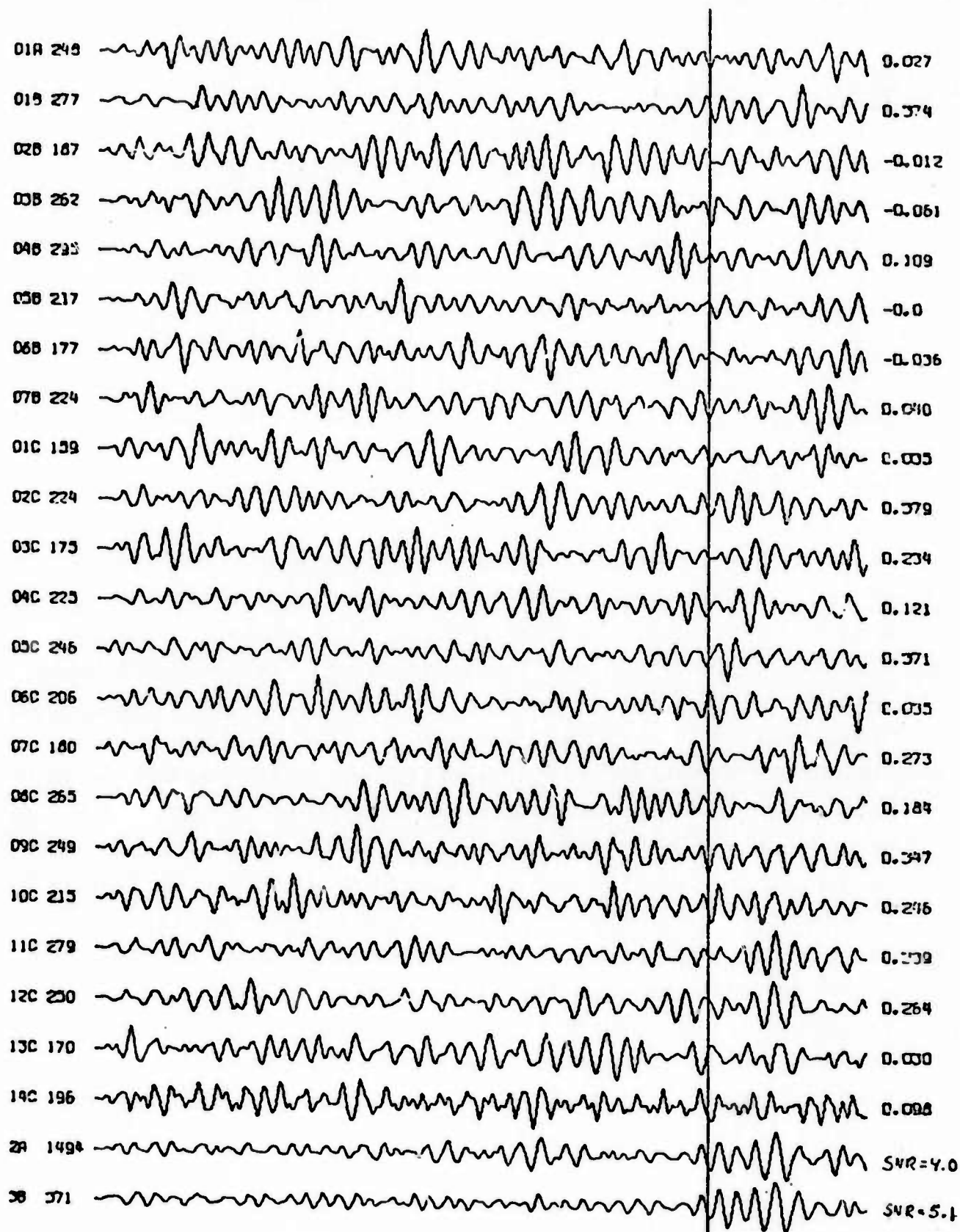use of the tests as signal-noise discriminants.

Fig. 4.1 Example of extreme noise wavelets. The column to the right
gives the $\hat{\gamma}_j$-weights. 2A and 3B denote array and weighted
array beam respectively, pointing south of Honshu, Japan.
The test results give high signal similarity and non-random
sign and size of the amplitude weights, but a check with the
amplitude pattern rejects this event as being an earthquake
in Japan area.

4.2 Precursors to PP

A detailed study of precursors to PP has been completed.
Extensive observational data from the NORSAR and Warra-
munga arrays has been analysed, and power within precursor
wave trains has been mapped as function of time, slowness
and azimuth. An example of the PP precursors at NORSAR
from an event in the Molucca Passage ($\Delta \sim 100^{\circ}$) is shown in
Fig. 4.2, and the power distribution in azimuth for a travel
time of 1025 sec is illustrated in Fig. 4.3. The observed
power variations for a wide range of travel times have been
compared with the results of a theoretical study of the
interpretation of PP precursors in terms of scattering by
small-scale random irregularities in the crust and uppermost
mantle. This comparison revealed that the scattering inter-
pretation offers a plausible and adequate explanation of the
detailed observational data, namely: onset times, duration,
slowness, azimuth and amplitude variations. The correspondence
between observed values and those predicted on the scattering
interpretation is evident from Fig. 4.3, in which theoretical
curves for T=1025 secs and two different upper mantle models
have been included. The scattering interpretation of PP
precursors has an important bearing on the interpretation
of the entire short period teleseismic P coda, and, moreover,
removes the need for postulating sharp reflecting discon-
tinuities in the uppermost few hundred kilometers of the
crust and upper mantle. This latter conclusion is also
supported by the results of a similar study of precursors
to PKPPKP which is nearing completion. This work has
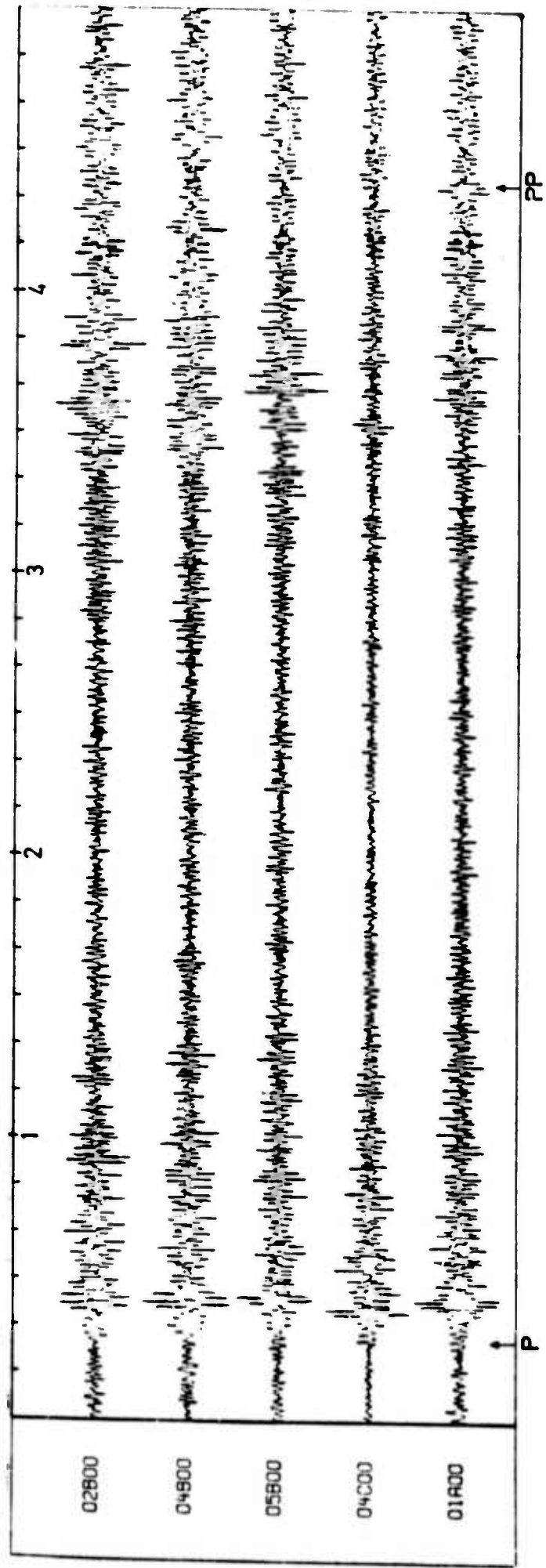been undertaken by D.W. King, R.A.W. Haddon and E.S. Husebye.

Fig. 4.2   Seismogram from 5 NORSAR subarray central instruments (as labelled) for an event in the Molucca Passage ($\Delta = 100^\circ$). The data has been filtered in the range 0.6 Hz to 3.0 Hz. Note the extended PP precursor wavetrain starting at about 2 mins 50 secs.
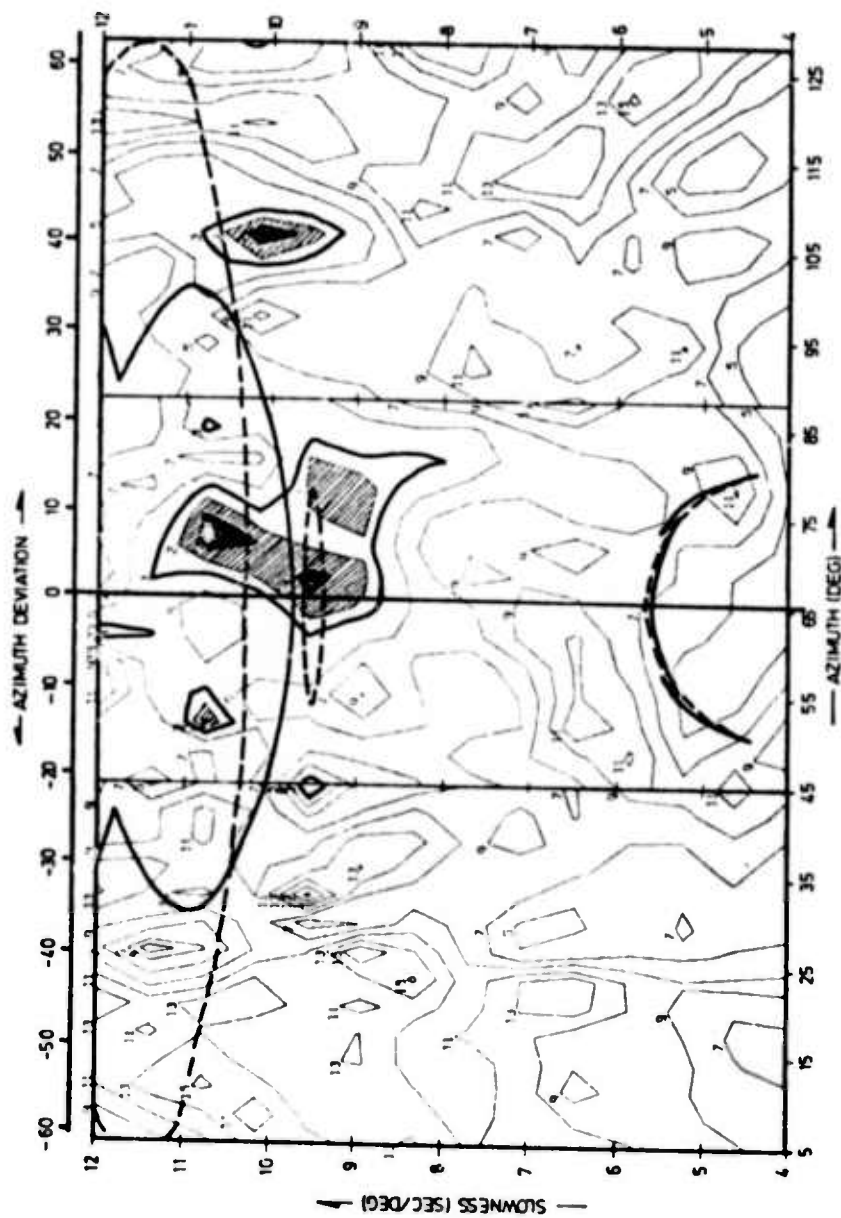
Fig. 4.3 Contoured beam power (p) values averaged over 3 seconds at travel time 1025 sec for the event in Fig. 4.2. The 3 dB contour is darkened, and enclosed power values are hatched (2 dB<p<1 dB) and dotted (1 dB<p<0 dB). Theoretical results for T=1025 secs and Δ=100° for the Jeffreys model (solid line) and SMAK II model (broken line) are plotted for comparison with the observed power distribution. Note the wide azimuthal spread of power at high slownesses.

4.3   In Situ Stress Monitoring

For some years now, the existence of narrow spectral peaks in the NORSAR short period recordings has been known and investigated. Several such peaks have been found and identified to have their origin in hydroelectric power plants, although some remain to be explained (Hjortenberg and Risbo, 1974).

A power plant near 14C has been found to generate a very strong spectral component at 2.78 Hz, corresponding to 166 2/3 rpm. This is now being used as a steady state energy source for possible monitoring of in situ stress changes. The six short period seismometers in 14C have a distance from the source ranging from roughly 2 to 12 km, and the analysis is done through a spectral analysis giving phase differences between stations. Fig. 4.4 gives an example where all station combinations have been plotted, and the value for each one is repeated for every 2π because the number of full wavelengths is not known. There appears to be a lineation corresponding to 5 km/sec which is a reasonable velocity for the distances involved in this experiment.

Using 15 minutes of night time data, spectral estimates have already been obtained with a phase angle stability of $\pm 2^{\circ}$, which corresponds to a precision of about 10^{-3}. The main restrictions here are the stability of the instruments (which is very good) and the signal-to-noise ratio. By adding more data, and possibly by inserting a clean reference signal at 2.78 Hz in one of the channels, we hope to be able to increase the precision to about 10^{-4}, which is very good for such large distances and about the level at which earth tides should be observed. This work has been undertaken by K. Aki and H. Bungum.
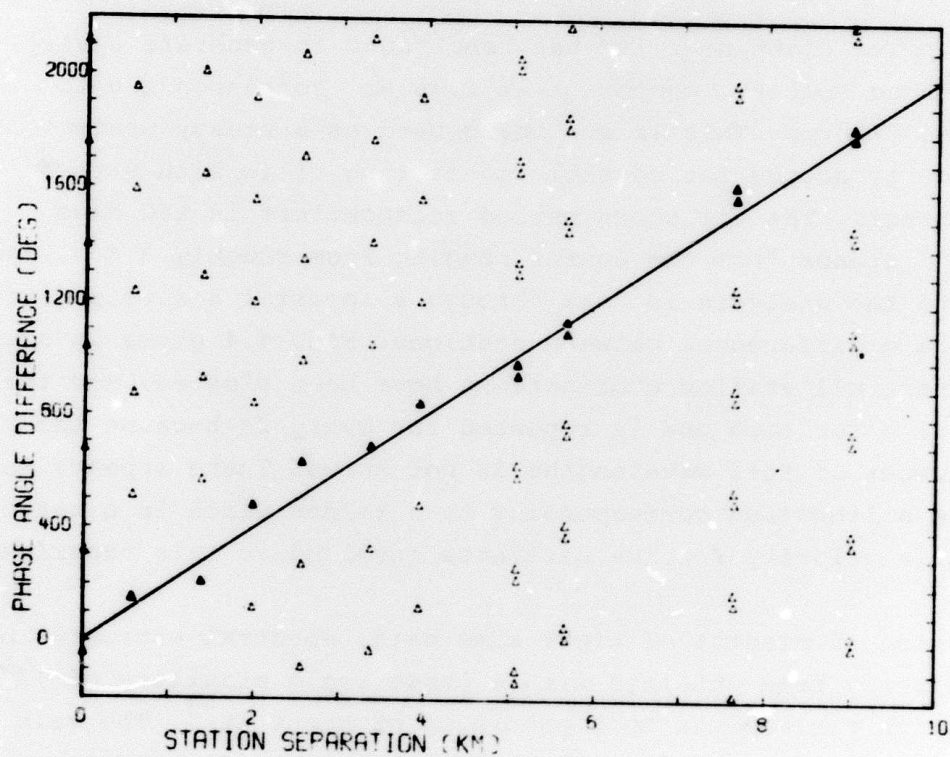
Fig. 4.4 Phase angle differences vs. station separation for the
2.78 Hz spectral component at 14C, plotted at intervals
of 360°. The straight line corresponds to a velocity
of 5.0 km/sec.

4.4 Autoregressive Analysis of Seismic P-wave Signals and
     Short Period Discrimination

A new short period discriminant between earthquakes and
underground nuclear explosions has been constructed. The
discriminant is based on second order statistical properties
of seismic P-wave signals. It is shown that the digitized
time series defined by a seismic P-wave signal can be split
into several sections, each of which is described statis-
tically by a lower order (order varying from 2 to 6
in most cases) autoregressive model. An autoregressive
model has the form

$$X(t) - a_1 X(t-1) - \ldots - a_p X(t-p) = Z(t)$$

where $X(t)$ is the short period data time series defined
by the P-wave signal, $Z(t)$ is a white noise time series and
p is the order of the model. The autoregressive representa-
tion of the signal has the advantage of concentrating the
power spectrum information into a few autoregressive para-
meters. The autoregressive analysis was carried out for
40 underground nuclear explosions and 45 earthquakes from
Eurasia. A plot of the two most significant autoregressive
coefficients is given in Fig. 4.5. At a later stage it is
our objective to examine the performance of multivariate
discriminants constructed by combining autoregressive
parameters with existing discriminants. This work has been
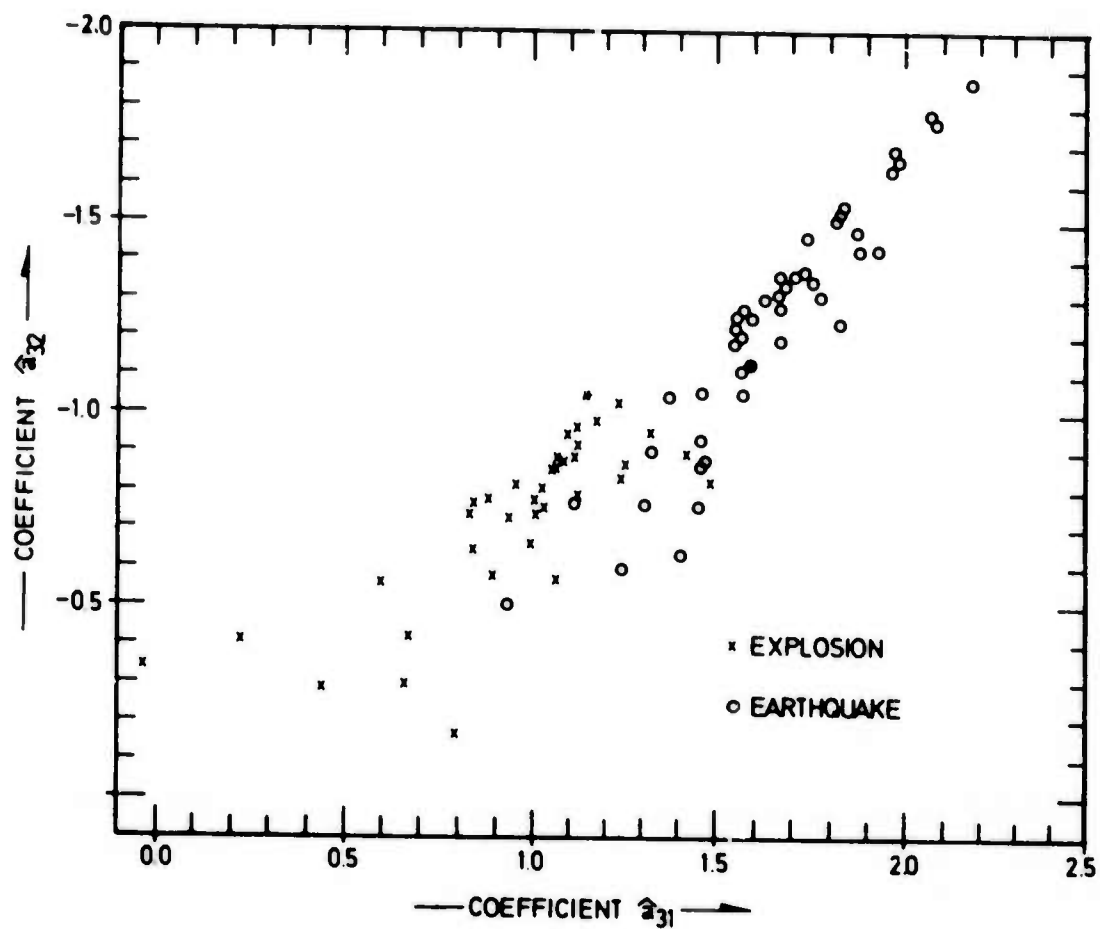undertaken by D. Tjøstheim.

Fig. 4.5 Estimated coefficients $\hat{a}_{31}$ and $\hat{a}_{32}$ assuming a 3rd order autoregressive model.

$$X(t) - a_{31} \, X(t-1) - a_{32} \, X(t-2) - a_{33} \, X(t-3) = Z(t).$$

5.   MISCELLANEOUS

5.1 Visiting Scientists
During the reporting period a number of scientists, whose
names are listed below, visited NORSAR Data Processing
Center, Kjeller, for various research purposes.

Dr. S. Gregersen and Dr. E. Hjortenberg, Dept. of Geodetics,
        University of Copenhagen, 15 - 25 October 1974

Lt. Col. N. Orsini and Capt. R.J. Woodward, 22 - 24 October
        1974

Professor Berckhemer, Institut für Meteorologie und Geophysik,
        Frankfurt, West Germany, 16 November 1974

Dr. Seppo Pirhonen, University of Helsinki, 9 - 20 December
        1974

Dr. Heikki Korhonen, University of Oulu, Finland,
        13 - 20 December 1974.

5.2 Doctoral Thesis
On 15 November 1974 Hilmar Bungum successfully defended
his Doctoral Thesis, Detection, Location and Identification
of Seismic Events Using the Norwegian Seismic Array, at
the University of Bergen.

5.3 Reports Completed
Berteussen, K.A., and E.S. Husebye: Amplitude Pattern
        Effects on NORSAR P-wave Detectability, NORSAR
        Scientific Report 1-74/75.

Berteussen, K.A.: Progress Report, 3rd Quarter 1974.

5.4 Papers Presented

The paper "Three dimensional seismic-velocity anomalies
in the crust and upper-mantle under the U.S.G.S. California
seismic array" by K. Aki, E.S. Husebye, A. Christoffersson
and C. Powell was presented by K. Aki at the Annual Fall
Meeting of the A.G.U. in San Francisco in December.

5.5 Data Tapes

87 data tapes were sent to the Seismic Data Analysis Center
in Alexandria, Virginia, in the fourth quarter of 1974.

6. REFERENCES

Fyen, J., E.S. Husebye and A. Christoffersson (1974): Signal-
noise classification, in press.

Hjortenberg, E., and T. Risbo: Monochromatic components of
the seismic noise in the NORSAR area, submitted to
Geophys. J.R. Astr. Soc.